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Retirement of Mr F. H. Bushby

When Mr F. H. (Fred) Bushby retired as Director of Services on 9 January 1984, the Office bade farewell to one of its most able and colourful characters who had served it with great success and deep commitment for almost 40 years.

Fred Bushby was an outstanding student, graduating from Imperial College with First Class Honours in mathematics in 1944 and taking both the Sir John Lubbock Memorial Prize and the Governors' Prize

in mathematics as the best student of his year. In normal times he would almost certainly have stayed on to do research but he joined the RAF Meteorological Branch in November 1944 and served at several stations at home and in south-east Asia whence he returned as a Flight Lieutenant for demobilization in early 1948. He then started his civilian career as a Scientific Officer in the Meteorological Office but it was his posting to the Forecasting Research Branch in Dunstable in 1950 that launched him on a remarkable career in numerical weather prediction spanning some 27 years with only one surprising break of $2\frac{1}{2}$ years as Chief Meteorological Officer in Aden.

In 1950 a remarkably far-sighted decision was made to send Bushby back to Imperial College for a course on numerical methods, including relaxation techniques, given by Sir Richard Southwell. In 1952 he attended a course on computing methods at Cambridge where the first EDSAC computer was being installed. Then, under the leadership of J. S. Sawyer, he wrote numerical programs to compute fields and tendencies based on Sutcliffe's ideas of development using a copy of the EDSAC machine built for J. Lyons & Co. at Cadby Hall. Sawyer and Bushby then proceeded to develop a so-called $2\frac{1}{2}$-dimensional numerical prediction model which produced its first forecast in 1954 using the Ferranti Mk I computer at Manchester University. This led to the construction of a 3-level geostrophic model which went ahead when the Office acquired its own Ferranti Mercury computer in 1959. However, since the performance of this machine, capable of only 3000 floating-point operations per second, was not much greater than a modern programmable pocket calculator, operational forecasts were not possible until the Office installed its second computer, an English Electric KDF9, in 1965. The first operational 48-hour forecast was issued on 2 November 1965 and marked a new era of forecasting in the Meteorological Office.

Meanwhile Fred Bushby had been recently promoted to Assistant Director in charge of the Forecasting Research Branch. I well remember this because, having been Director-General for only a few days, this was my first important decision, and when my advisors suggested that Fred was too young to be promoted ahead of many of his seniors, I gently reminded them that he was only five months younger than I but with a good deal more meteorological knowledge and experience! The Office soon recovered from the initial shock and Fred Bushby entered a very important and successful phase of his scientific career.

Since 1963, ably supported by Mavis Hinds and Margaret Timpson, he had been developing a very advanced 10-level primitive-equation model formulated well ahead of its time by John Sawyer. This was designed to predict the development of fronts and make the first quantitative forecasts of precipitation on a fine-mesh, 100 km, horizontal grid. For this Bushby was quick to exploit the greater computing power of the new Ferranti ATLAS computer at Harwell, which was capable of about one million instructions per second, and he soon established himself as one of the most gifted and resourceful users of advanced computers in the country. The fine-mesh model was later stretched to cover most of the northern hemisphere on a coarser grid and both were ready for operational testing when we acquired the very fast IBM 360/195 computer in 1971. Their impact on the quality of general forecasts for up to three days ahead and of rainfall forecasts for up to 36 hours ahead was marked and immediate and put the UK in the world forefront of numerical weather prediction. Both the scientific reputation and public image of the Office were thereby enhanced and a good deal of the credit must to to Fred Bushby whose foresight, initiative and single-minded dedication to achieving his clear-sighted objectives were an inspiration to his young colleagues and to the senior management alike.

In 1974 his achievements were marked by promotion to Deputy Director in charge of Dynamical Research. With this wider remit he was able to encourage the development of even more advanced models for numerical weather prediction, climate simulation and stratospheric studies, all on the global scale. In 1977 he was transferred to the post of Deputy Director Forecasting Services in preparation for his ultimate promotion to Director of Services in 1978.

During the last four years Fred Bushby has applied his wide experience, knowledge and enthusiasm to guiding the Services Directorate through a difficult period when ever-increasing demands for its services have had to be met by an ever-decreasing staff. A doer rather than a philosopher, his resilience, shrewd judgement and far-sightedness have been great assets and although he sometimes revelled in combative argument, especially with his erstwhile research colleagues, he would always, in the end, agree to what was best for the Office as a whole. Indeed the Office was the centre of Fred's life and I am grateful for his unfailing support and many personal kindnesses. He had a genuine interest and concern for the staff at all levels and, being widely known throughout the Office, he will be the subject of many stories — some apocryphal, mostly true — wherever meteorologists meet and reminisce.

In the computer world Fred Bushby was well known and greatly respected as one of the most experienced and knowledgeable users of giant machines. In international meteorology his advice was much appreciated especially in the WMO/ICSU Working Group on Numerical Experimentation and on the Scientific Advisory Group of the European Centre for Medium Range Weather Forecasts.

Outside meteorology, Fred's main passion is bridge; in 1981 he reached the high-point but, we hope, not the apogee of his career when, with Colin Flood, he reached the last 16 in the National Championships.

I am sure that all his colleagues will wish to join with me in wishing Fred and Joan many years of happiness and time to enjoy their common, but not identical, enthusiasms for cricket and other club activities.

B. J. Mason

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Applications of automated weather radar and Meteosat displays in an aviation forecast office

By B. J. Booth

(Meteorological Office, Royal Air Force Lyneham)

Summary

During June 1982 a digital framestore and colour TV monitor were installed in the meteorological office at Royal Air Force Lyneham. The equipment stores and displays preprocessed digital Meteosat or weather radar data, which can be replayed in sequence by the recipient. Using case studies this paper describes some of the situations in which automated displays can provide, and have provided, valuable analytical and briefing material for the aviation forecaster.

Introduction

During the last decade the Meteorological Radar Research Laboratory (Met O RRL) Malvern, has expended a considerable amount of effort in developing an automated weather radar network (Browning 1980). Although it was appreciated at its inception that data from such a network would be of great value to the forecaster (Taylor and Browning 1974), until recently the main beneficiaries have been such bodies as water authorities. This in part arises from the network's natural development, which has required much of the research effect to be directed toward (a) the quantification of both radar and satellite data in terms of precipitation intensity, and (b) the presentation of these quantities in an easily assimilated format, as shown, for instance, on the cover of the April 1980 issue of *Weather* or by Hill (1982).

Detailed descriptions of the network have appeared elsewhere, for example Browning and Collier (1982), so for the purposes of this paper it is sufficient simply to state that data from both Meteosat and a network of radars is processed into digital format at the Met O RRL, then automatically transmitted in near real time along standard telephone lines to the user's display equipment, which consists of a digital framestore and colour TV monitor (Ball *et al.* 1979). At the present stage of development only one type of data (Meteosat or network rainfall radar) can be received at any one time, but the data type sent to Lyneham can be changed manually by Met O RRL at the request of the recipient.

As previously remarked, non-aviation operators have been the major beneficiaries of the automated weather radar network, but since June 1982 the data have been relayed to the Meteorological Office at Royal Air Force Lyneham, the main transport base of the Royal Air Force, for evaluation in an operational aviation environment. This location is ideally suited for the task since Lyneham's resident Hercules squadrons fly over 10 million air miles in an average year, in a wide variety of roles, ranging from 2 to 4 hour low-level (250 ft above ground level) flights which often involve the dropping of troops or freight by parachute, to 8 to 14 hour non-stop trooping/freight flights direct to such diverse destinations as Bahrain, Canada or Ascension Island. Some Hercules have an air-to-air refuelling capability and as a consequence a considerable amount of time is spent practising the necessary skills. In addition both civil and foreign aircraft are frequent visitors to the base.

Besides meeting the various meteorological requirements of aircraft operating from Lyneham, the meteorological office is also responsible for the supply of meteorological information to another seven military airfields/establishments and three civilian airfields (operating light aircraft, gliders or hot-air balloons) within a 40 km radius (Fig. 1). Consequently, although up to 60% of briefings take place face to face, a substantial number are given over the telephone.

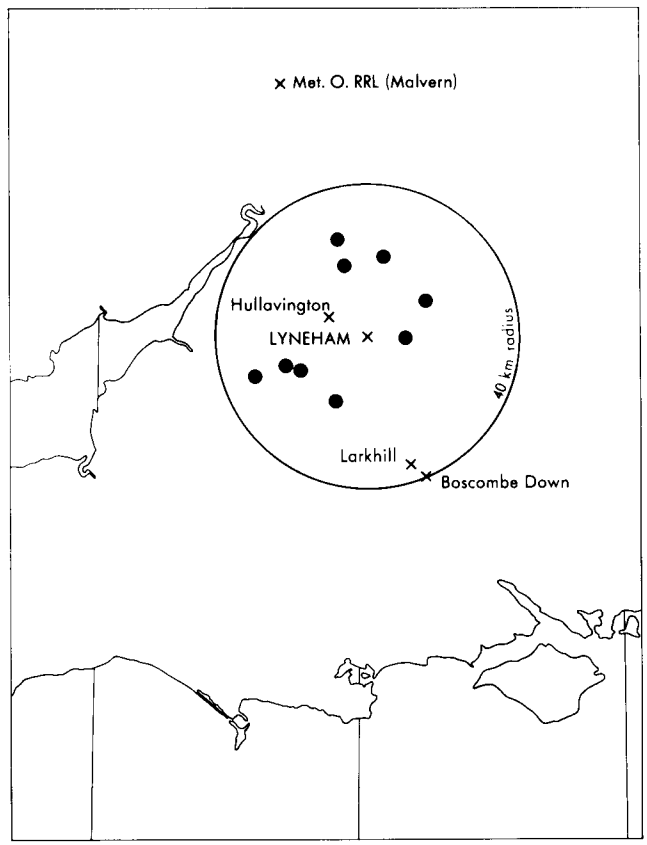

Figure 1. Sites of airfields and other establishments dependent on Lyneham meteorological office for meteorological services. Named sites (×) are referred to in the text.

Since only one forecaster is on duty at any one time at Lyneham, such a diverse forecasting requirement demands a constant adjustment of thought processes from local to international meteorological problems which in turn requires frequent reference to the latest synoptic chart or telecommunications data. The former presents data which are at best 80 minutes old ($H+80$) when placed in front of the forecaster and is rarely updated until $H+140$ minutes ($H=$ data time). At Lyneham this means that in exceptional circumstances a fast-moving system, identified at the edge of a chart, data time H, may reach the airfield before the subsequent chart ($H+60$ minutes) is received some two hours after H.

On the other hand, whilst the meteorological telecommunications network disseminates coded weather messages rapidly, the presentation is not conducive to forming a mental picture of the situation. These are problems common to all aviation forecast offices and clearly an automated display system which can present near-real-time information on precipitation or cloud distribution, can only improve a forecaster's ability to react both rapidly and confidently to those awkward questions which always seem to be asked at briefings.

With this in mind the Lyneham display unit is prominently positioned in the forecast office and, because of the bright colours of the display, the forecaster is constantly aware of the current precipitation or cloud distribution, since one or the other is always on view.

Radar network rainfall data

The rainfall data, covering most of England and Wales (Fig. 2), are received at 15-minute intervals, usually within 10 minutes of data acquisition, and are displayed in an array of 5 km square grid squares (pixels). Every alternate picture (at $H + 15$ minutes and $H + 45$ minutes) is placed in the digital frame-store — a maximum of four pictures covering a period of 1½ hours. These can be replayed in sequence at various speeds by the local operator.

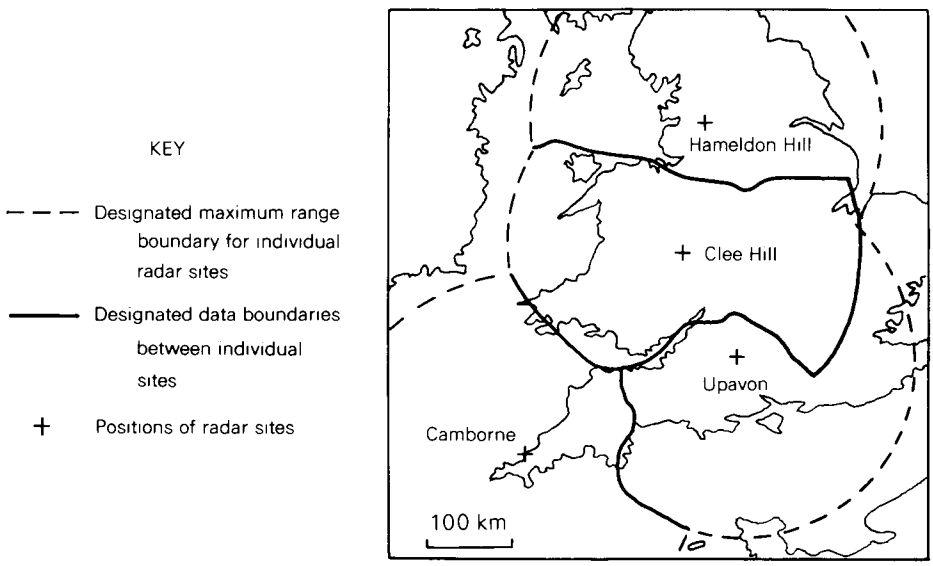

Figure 2. Maximum radar coverage displayed on the TV colour monitor and locations of the four radars in current operational use.

The colour of each pixel indicates the mean rainfall intensity within that pixel at data acquisition. Eight intensity levels can be displayed and these together with the colour scheme adopted at Lyneham are shown in Table I.

Table I. *Rainfall intensity levels and colour scheme adopted at Lyneham.*

Intensity level	Rainfall intensity (mm h^{-1})	Colour
0	$<\frac{1}{8}$	Black
1	$\frac{1}{8}$ to <1	White
2	1 to <4	Yellow
3	4 to <8	Green
4	8 to <16	Cyan
5	16 to <32	Blue
6	32 to <126	Violet
7	$\geqslant 126$	Red

For reference purposes a background coastline map is provided electronically, together with a pair of movable 'crosswires'.

As it is an operational airfield there is little call at Lyneham for quantitative assessments of rainfall, so the data have necessarily been utilized in other ways.

Cloud and visibility

While rain itself is not normally a hazard to low-flying aircraft, the associated conditions of poor visibility and/or low cloud are. Although the display unit cannot present specific data on these variables, by assuming that observed relationships (from routine synoptic observations) between precipitation and cloud and/or visibility apply to most of the precipitation area, at least the extent of the hazardous conditions may be inferred. This can be particularly useful when preparing forecasts for low-level flights over data-sparse areas (such as central Wales) especially when frontal movement has been slow and erratic.

Icing and turbulence

Hazards to aircraft flying at higher levels are generally of a different nature — icing and turbulence being the main causes for concern, especially when associated with convective cloud. Although on-board weather radar enables aircraft to circumnavigate such areas, prior knowledge of their existence and location is useful to crews.

Once again the system does not provide specific information, but occasionally, as on 12 November 1982, areas of intense precipitation within a frontal rainbelt can indicate embedded convective activity and hence associated icing and turbulence.

In this instance a very active eastward moving cold front crossed Wales, then England, at 45 to 50 km h^{-1}. At Lyneham the frontal passage between 0500 GMT and 0600 GMT (Fig. 3) was accompanied by a burst of very heavy rain, a wind veer from 190° to 230° and a 3.5 °C fall in temperature.

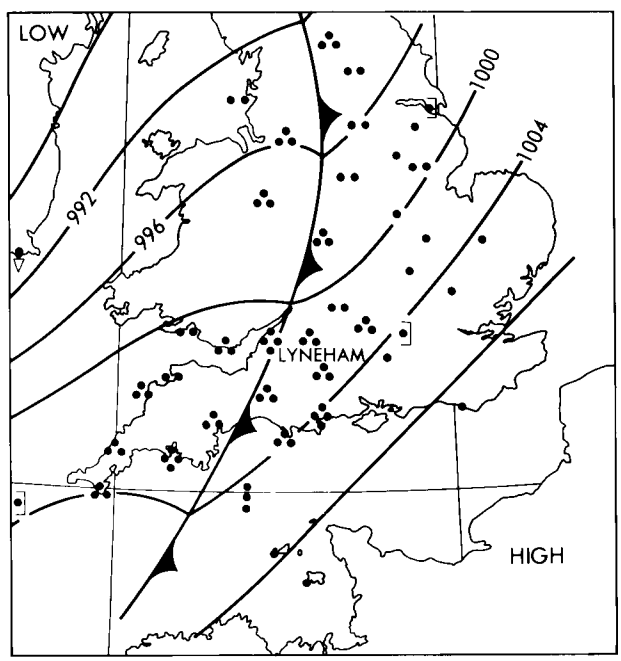

Figure 3. Synoptic chart for 0500 GMT on 12 November 1982, approximately one hour before the cold front reached Lyneham. Although the rain area is clearly extensive, there is no indication that a squall-line has developed or of the extent of the rain over Wales. This chart would have been handed to the forecaster, unanalysed, at approximately 0610 GMT.

As can be seen from the 0400 GMT precipitation distribution picture, Plate I, the rain area associated with the cold front at this time was extensive and, although embedded convective precipitation was evident over Wales, the distribution must be considered irregular. During the following hour, however, these convective elements became organized along the line of the surface front as a line squall developed, Plate II, and this feature, with rainfall intensities exceeding 32 mm h^{-1}, was followed to the periphery of the radar coverage.

Remembering that at 0610 GMT (the reception time of the 0600 GMT precipitation distribution picture) the forecaster would still have been briefing from the 0400 GMT synoptic surface chart (data time 0350 GMT), this is an excellent example of the system (even with only 50% of normal radar coverage) providing not only an early indication of developments but also the means to follow them in real time.

Thunderstorms

The loading and refuelling of aircraft at Lyneham, together with the flying of balloons for parachute training at nearby RAF Hullavington, are particularly sensitive operations in thundery weather. Consequently, there is a requirement to provide, and continuously review, forecasts of lightning risk.

While forecasters' confidence in their predictions has greatly improved in this context, due to their ability to track thunderstorms with the automated display system, the speed of *in situ* development and decay of convective precipitation has emphasized the care needed in interpreting the displays in thundery situations.

For example, a line of thunderstorms developed very quickly just south of Boscombe Down between 0715 GMT and 0730 GMT on 14 July 1982, and its northward movement was subsequently monitored in near real time on the precipitation display. Although conventional surface observations gave no indication of renewed thundery activity to the south of the trough line, it was clear from the 0830 GMT precipitation distribution picture (not reproduced) that a small detached convective cell was developing to the south-east of Lyneham in a previously precipitation-free area.

Normally this period of the morning is a very busy one for the airfield authorities, with frequent movements, but on this occasion the schedule had been seriously disrupted as the threat of thundery weather had delayed the refuelling and loading of aircraft. Consequently the forecaster was under intense pressure to forecast a lower risk of lightning once the precipitation display showed the trough line clear of Lyneham at 0900 GMT, Plate III. In view of the developing small cell to the south-east he refused to bow to the pressure and his caution was justified when, just after 0930 GMT another thunderstorm crossed the airfield, Plate IV.

This was a good example of the speed with which convective cells decay. At 0915 GMT (picture not reproduced) the maximum precipitation intensity of this cell was 16 to 32 mm h^{-1}, yet by 1000 GMT the cell had completely disappeared.

TREND* forecasts

The usefulness of the precipitation distribution displays in preparing TREND forecasts is rather limited since changes in visibility and/or cloud conditions are normally of prime importance. None the less, improvements associated with the passages of cold fronts have been forecast with accuracy, while in unstable situations preferred shower tracks can be identified and TRENDS forecast accordingly.

*A TREND is a 2-hour landing forecast which is routinely added to hourly observations at some airfields.

Meteosat data

The Meteosat data, displayed in an array of 10 km pixels, cover an area bounded by approximately 45°N to 56°N and 03°E to 13°W, Fig. 4. As with the network radar rainfall display, the Meteosat display incorporates a background coastline map and a pair of moveable crosswires for reference purposes.

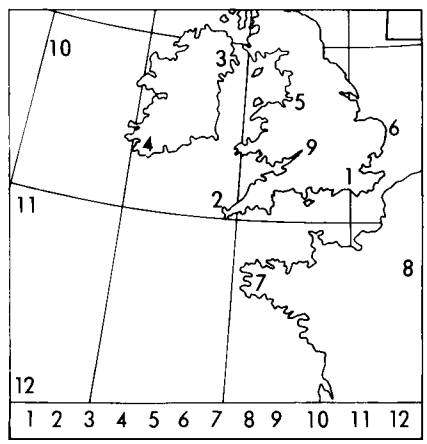

Figure 4. Area covered by Meteosat infra-red imagery. The data time is presented in the top right-hand corner. Spot temperatures for the numbered locations on the map are presented in sequence along the bottom strip.

Although both half-hourly visual and infra-red (IR) Meteosat data are available, it was decided at a very early stage to use hourly IR data only. This decision was based on the following circumstances:

(i) Visual pictures are unavailable during the hours of darkness, whereas IR pictures would provide a continuity of data;

(ii) The limited storage facility of the unit (only 4 pictures can be stored);

(iii) The relatively greater potential of obtaining quantitative detail from IR data (such as inferring cloud top heights from cloud top temperatures).

The mean IR intensity level for each 10 km pixel is displayed as the equivalent black body temperature (in degrees Celsius), each temperature being colour coded. In practice, since the TV monitor is capable of generating only eight colours, each colour must necessarily relate to a wide range of temperatures. Table II shows the colour coding and temperature relationship initially adopted at Lyneham.

Table II. *Temperature–colour relationship adopted at Lyneham for presentation of Meteosat infra-red imagery.*

Colour	Temperature range (°C)	Approximate height band (feet × 1000)
Black	>20	Surface
Yellow	15 to 20	<2
Green	8 to 15	2 to 7
Cyan	-5 to 8	7 to 14
Blue	-20 to -5	14 to 21
Violet	-33 to -20	21 to 27
Red	-45 to -33	27 to 33
White	<-45	>33

Unfortunately this proved too coarse a resolution to relate colours on the display unit with specific cloud top heights with any degree of accuracy, and subsequent modifications to the temperature ranges did little to help matters. The problem has, however, been partly overcome by embedding spot temperature values, coincident as far as possible with radiosonde stations, in a predetermined order, at the bottom of each picture, Fig. 4. Reference to the corresponding upper-air ascent then allows the cloud top height to be determined.

Some idea of the accuracy to be obtained can be gained by referring to the situation on 21 January 1983 when England was covered by a sheet of stratocumulus. Surface observations for 0700 GMT and 0800 GMT indicated a cloud base over Wiltshire of between 2300 and 2500 ft asl (above mean sea level), measured by cloud base recorder. Although a Lyneham aircraft reported the stratocumulus base and tops as 3000 and 4000 ft asl respectively at 0752 GMT, it is believed these figures were too high by 500 ft, in view of the consistent surface observations of cloud base, which implied an observed cloud top of 3500 ft asl.

This would be consistent with the 0724 GMT Larkhill ascent, Fig. 5, which shows a very strong inversion at this level. The temperature of the cloud top at the base of the inversion was -5.5 °C; the corresponding temperature measured by Meteosat was -5 °C. (In a similar situation at 0800 GMT on 7 March 1983 a Meteosat cloud top temperature of -1 °C compared very favourably with a Larkhill measurement of -0.2 °C.)

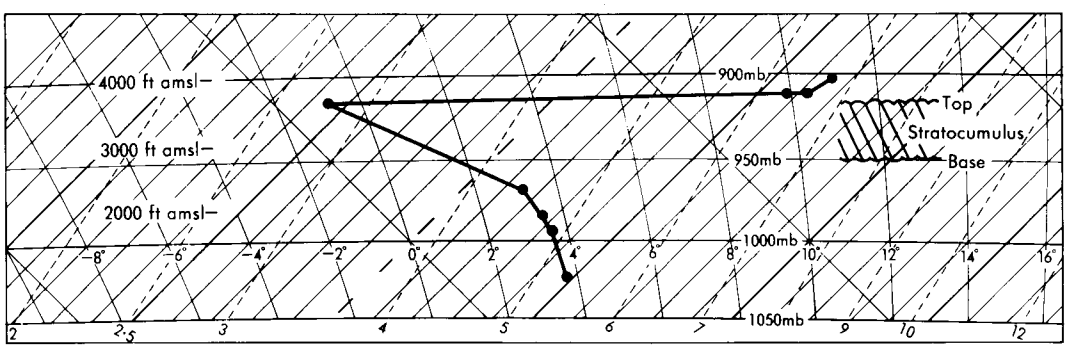

Figure 5. Larkhill ascent for 0724 GMT on 21 January 1983.

As a briefing aid the Meteosat display has time and again proved invaluable, even immediately following its introduction to Lyneham in the early summer of 1982. During this period some crews were receiving intensive training in air-to-air refuelling, which must of necessity be carried out in clear air, either above or between cloud layers. At the time Meteosat was only of limited use since, although totally cloud-free areas could easily be located, the coarse temperature resolution necessarily adopted made it difficult to identify with any accuracy the height of cloud tops.

Even with this limitation Meteosat was of some use when briefing an air-to-air refuelling exercise on 11 July 1982. At the 1300 GMT briefing, the crews were insistent the exercise should take place over south-west England, despite the 1200 GMT Meteosat display showing a large area of slow-moving layer cloud with embedded cumulonimbus just to the west. Having advised the crew that the North Sea would be a more suitable operational location, the forecaster suggested the safest area to the south-west (of Lyneham) to be over Devon or Somerset.

The 1300 GMT Meteosat display (received after the briefing) showed that not only had the cloud mass already reached the proposed area, but additional cumulonimbus development was taking place to the south. All this information was passed to the crews in ample time to allow a change of plan.

In another instance on a fine sunny morning a few days later, on 18 July 1982, the duty forecaster was confidently able to dissuade a glider pilot from attempting a flight from Hullavington to Lincolnshire, as it was clear from the automated Meteosat display that a south-eastwards moving stratocumulus sheet would soon cover the planned route and inhibit thermal activity.

Normally wave cloud would be difficult to identify from the Meteosat display but on 2 September 1982 a stationary detached cloud just to the lee of the Pennines attracted attention, Plate V. The cloud-top temperature was estimated to lie between -20 °C and -33 °C (approximately 21 000 to 27 000 ft), but Met O RRL subsequently assessed it as about -26 °C, ±2 °C (at 24 000 ft).

Although the wind at this level was in excess of 128 km h^{-1}, the leading edge of the cloud remained stationary from 1200 GMT to 1500 GMT, Plates V and VI, and in fact could be identified in the same position for nearly 24 hours, despite being hidden at times by eastward moving cirrus. This lack of movement indicated that the cloud was orographic in origin and, as the 1200 GMT Aughton ascent, Fig. 6, shows, conditions were indeed favourable for lee-wave development.

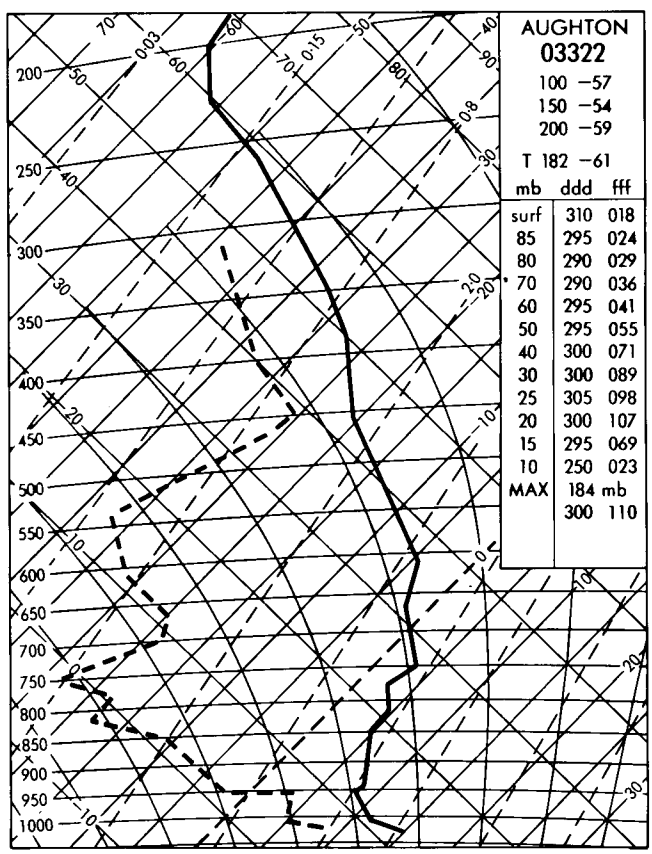

Figure 6. Aughton tephigram for 1200 GMT on 2 September 1982. 400 mb approximately equates to 24 000 ft. Wind data in degrees and knots.

Following Casswell (1966) it has been calculated that the maximum vertical velocity of a secondary wave train would have been found at 24 000 ft (temperature −26 °C) just above a layer of relatively high relative humidity and consistent with the 'observed' cloud-top temperature.

Since the two types of display offer unique data sets which complement routine synoptic observations it would be unwise to suggest that one is of greater use than the other. A case in point was the afternoon of 4 June 1982 when scattered thunderstorms developed in a warm unstable southerly surface airflow.

Conventional surface observations suggest the thundery activity is confined to eastern districts, Fig. 7. (The shower reported at Boscombe Down was unconnected with deep convection and lasted for all of a minute!) The corresponding precipitation display, Plate VII, shows evidence of convective precipitation over North Wales, the Vale of York, north Devon and along a line from Bristol to London, with a suspicion of storms over the Cherbourg peninsula and the Wash. The return over west Cornwall is believed to be spurious.

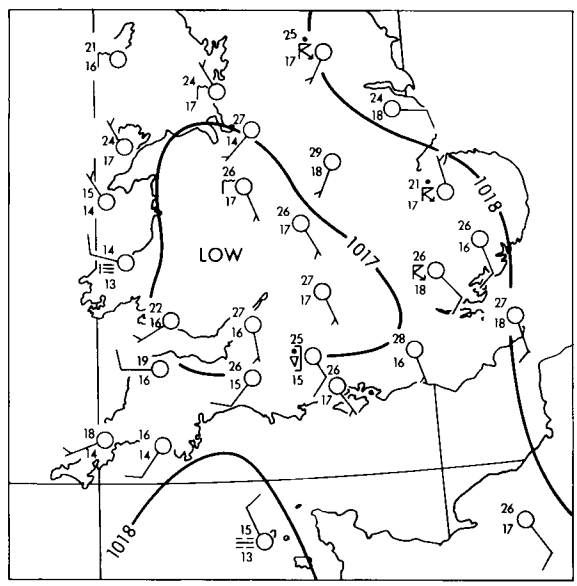

Figure 7. Synoptic chart for 1500 GMT on 4 June 1982. Plotted observations have been abbreviated to show wind, weather, dry-bulb and dew-point temperatures only.

The 1500 GMT Meteosat display, Plate VIII, clearly shows the locations of all cumulonimbus clouds (and hence thunderstorms) over England and Wales as well as France, plus the smaller convective cell over north Devon.

Despite high inland temperatures only small amounts of shallow cumulus developed over south and south-east England (possibly owing to the inland penetration of sea air), hence the black colouring indicating surface temperatures of more than 20 °C (actual screen temperatures 25–27 °C). The yellow colouring over the Midlands is indicative of larger cloud amounts. Although screen temperatures were similar to those further south, the mean areal radiance levels monitored by Meteosat would be lower owing to the presence of convective cloud, hence the yellow colouring (equivalent black-body temperature range 15–20 °C).

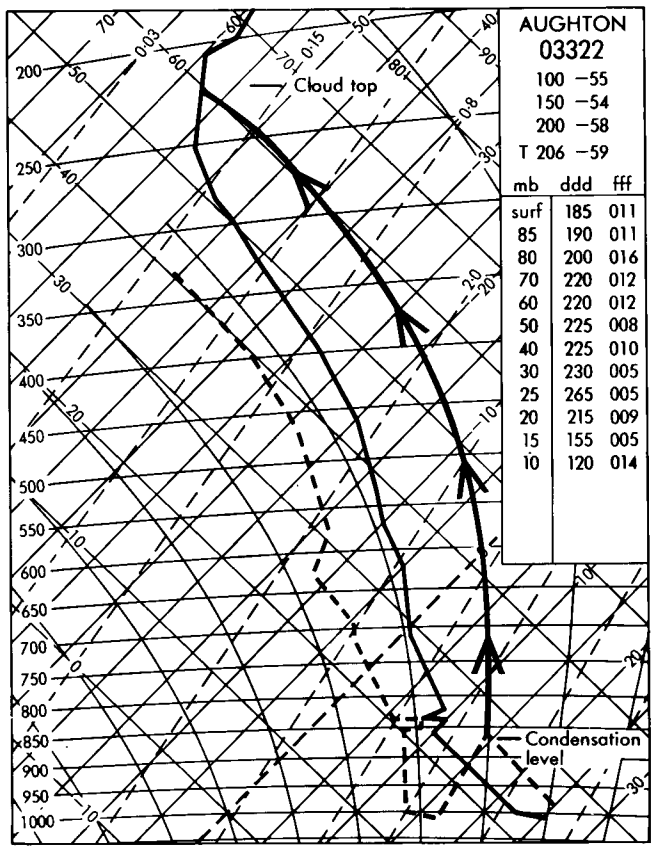

Figure 8. Aughton ascent for 1300 GMT on 4 June 1982. If the surface dry-bulb temperature at 1500 GMT is taken as 27 °C and the dew-point temperature as 17 °C, cloud tops can be estimated as reaching 36 000 ft.

Cumulonimbus cloud-top temperatures over England and Wales were assessed by Met O RRL as −56 °C (±2 °C), a height of 34 000–36 000 ft on the representative radiosonde ascents. This is consistent with cloud tops of 36 000 ft estimated by conventional means, as demonstrated by Fig. 8.

Thus while the precipitation display presents data at frequent (15 minute) intervals, the Meteosat display offers similar data (but less frequently) for a much greater area by inference from the cloud type and distribution, together with a good indication of the cloud-top heights. Additionally, and importantly from the aviation forecaster's point of view, it presents the weather situation with great visual impact.

Conclusion

In the short period that digital Meteosat and precipitation data have been made available to Lyneham all forecasters have found the information invaluable for analysis, while the ability to replay stored data has given much greater impact to their verbal briefings.

Acknowledgements

I am indebted to the staff of Met O RRL in general and to Dr A. Eccleston in particular for the advice they have offered and the provision of the photographs. I would also thank the Lyneham forecasters for bringing the several events to my attention.

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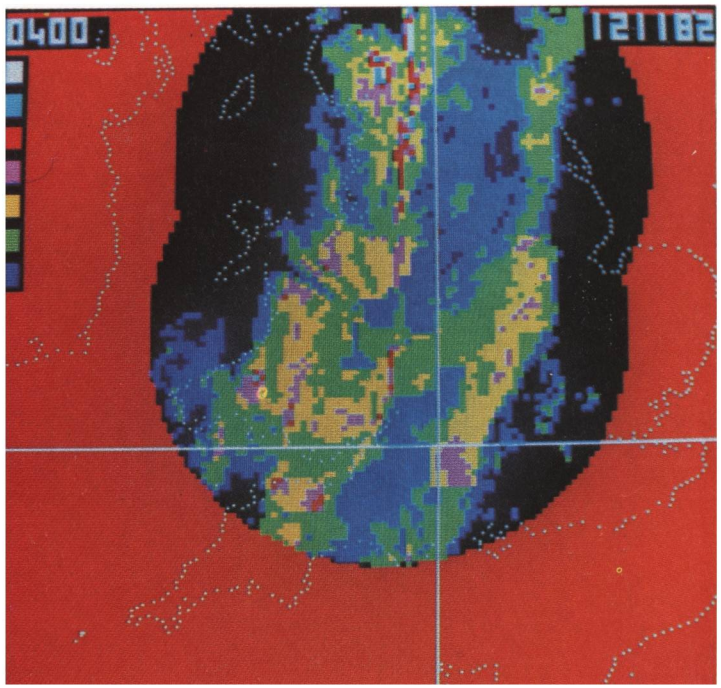

Plate I. The precipitation distribution display for 0400 GMT on 12 November 1982 (Upavon and Camborne radars were unserviceable). The intersection of the cross-wires locates Lyneham. Note the irregular distribution of heavy rain (violet/red/cyan) pixels over Wales. The colour scheme is different from that normally adopted at Lyneham, and on this presentation rainfall intensities (mm h^{-1}) are represented as follows: blue <1, green 1 to <4, yellow 4 to <8, violet 8 to <16, red 16 to <32, cyan 32 to <126, white $\geqslant 126$.

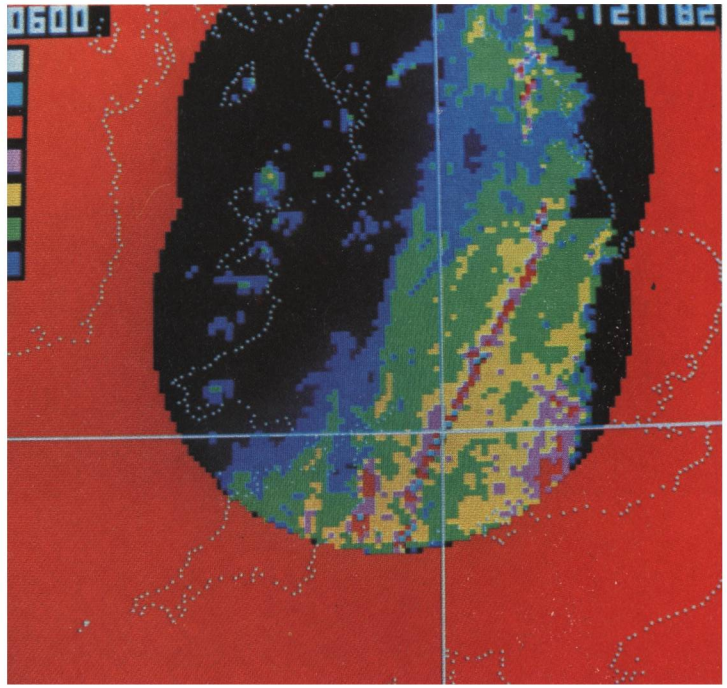

Plate II. The location and extent of the developing squall line is clearly evident in this precipitation distribution display for 0600 GMT on 12 November 1982. See Plate I for details of the colour scheme.

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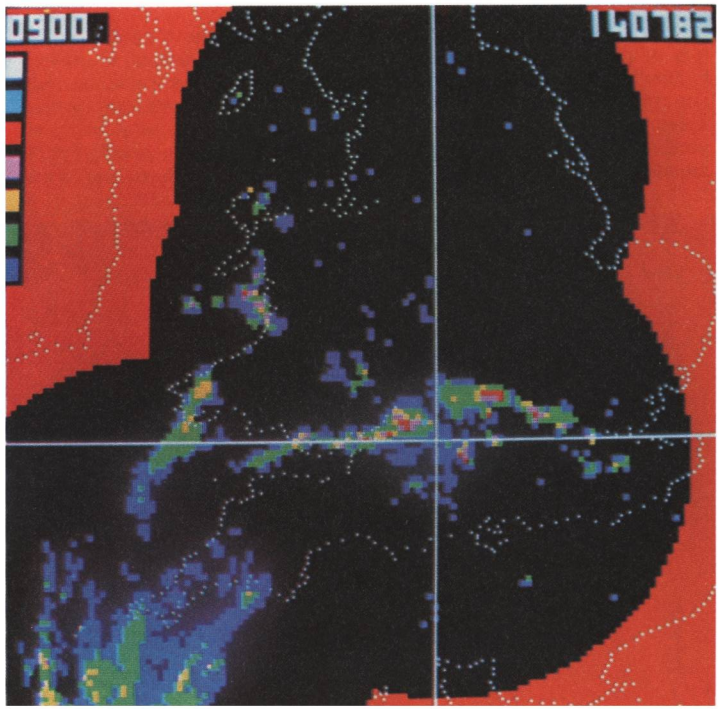

Plate III. The precipitation distribution display for 0900 GMT on 14 July 1982, which shows a significant line of showers and thunderstorms just to the north of Lyneham. However, by this time the forecaster's interest had been transferred to the small, but intense, echo to the south-east of the airfield (the violet/red pixels). This cell was not detectable from conventional surface observations. The blue/green pixels between Lyneham and the south coast are spurious echoes. See Plate I for details of the colour scheme.

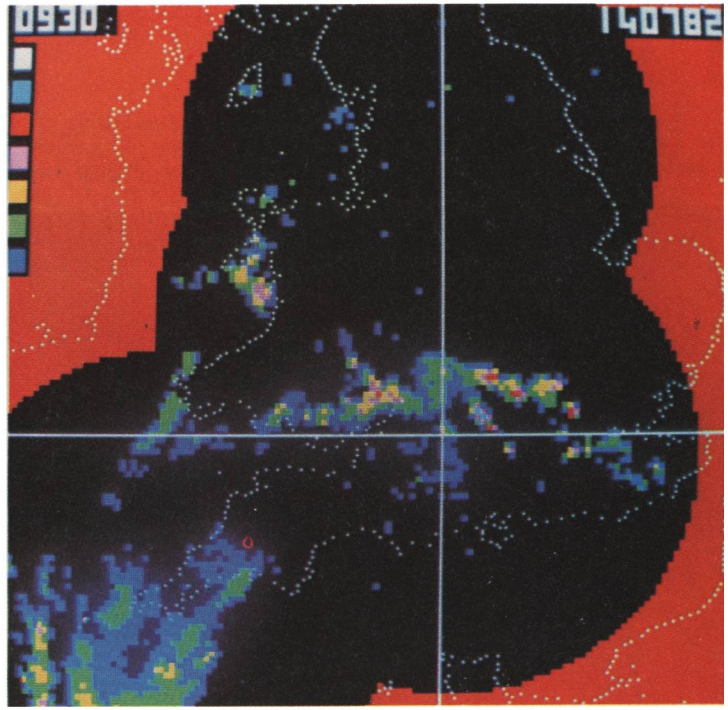

Plate IV. The precipitation distribution display for 0930 GMT on 14 July 1982, showing the echo referred to in Plate III crossing Lyneham. (Because of its limited extent the echo is almost obliterated by the cross-wires.) Although the mean areal rainfall intensity has now fallen to 4–8 mm h^{-1}, thunder and lightning were associated with the cell as it crossed the airfield. See Plate I for details of the colour scheme.

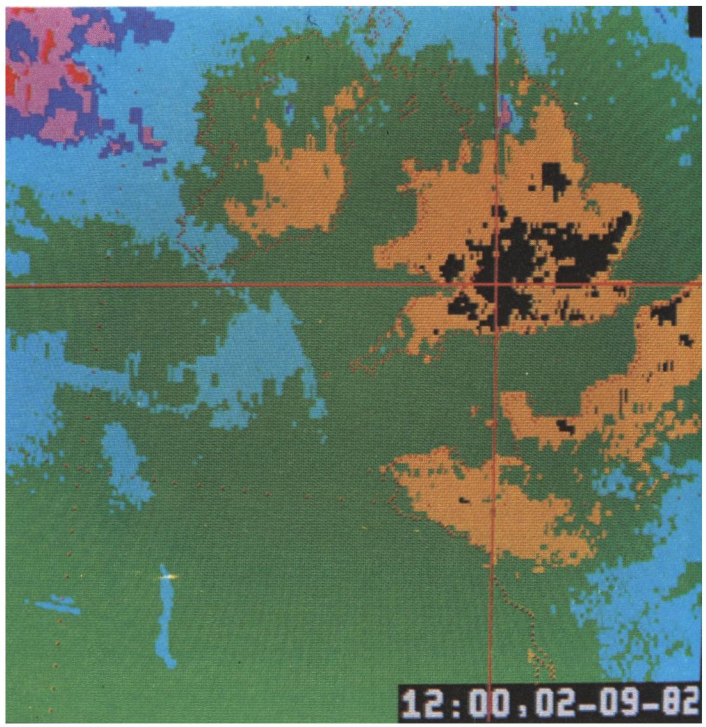

Plate V. Meteosat infra-red image at 1200 GMT on 2 September 1982. The cross-wires intersect over Lyneham, and the leading edge of the orographic cloud over the Pennines is aligned along the N–S cross-wire. The colours represent the following temperature ranges (°C): black >20, yellow 15 to 20, green 8 to 15, cyan −5 to 8, blue −20 to −5, violet −33 to −20, red −45 to −33, white <−45.

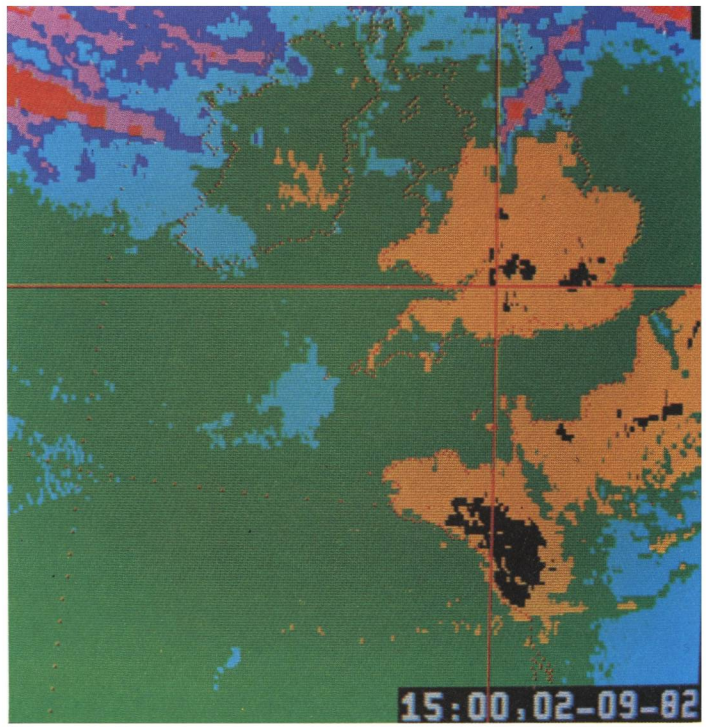

Plate VI. Meteosat infra-red image for 1500 GMT on 2 September 1982. The orographic cloud over the Pennines is still evident despite more widespread cirrus development. See Plate V for details of the colour scheme.

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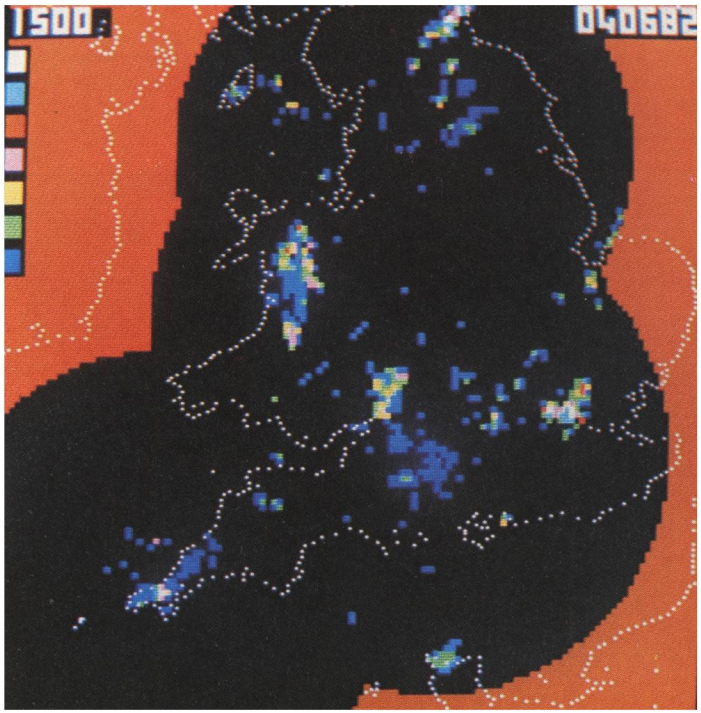

Plate VII. The precipitation distribution display at 1500 GMT on 4 June 1982, showing the locations of thunderstorms and showers. The returns over Cornwall and Salisbury Plain are spurious. See Plate I for details of the colour scheme.

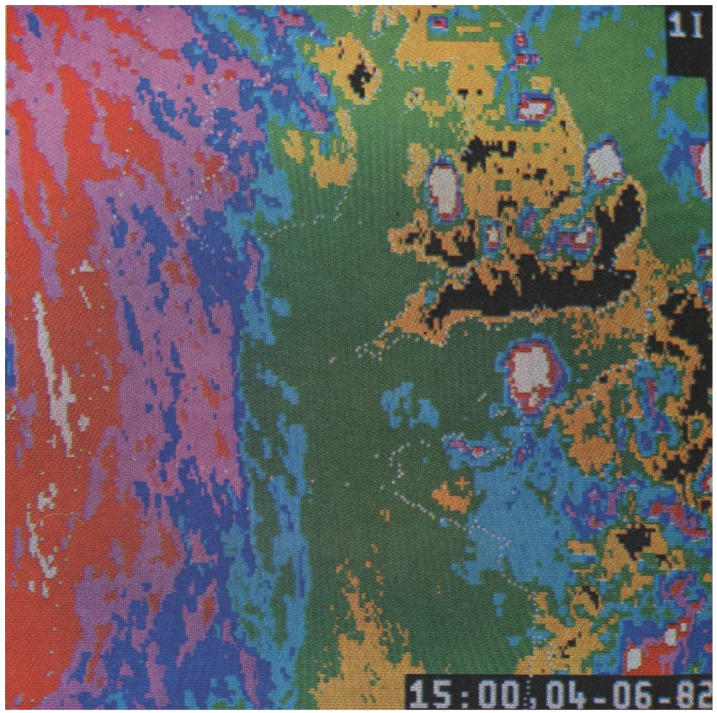

Plate VIII. Meteosat infra-red image at 1500 GMT on 4 June 1982, clearly showing the locations of cumulonimbus clouds over France and the southern North Sea, as well as England and Wales. The white pixels indicate the cumulonimbus tops. See Plate V for details of the colour scheme.

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Correspondence

Comments on 'Extreme value analysis in meteorology' by R. C. Tabony

In his paper on extreme value analysis in meteorology, Tabony (1983a) discusses the problem of seasonal variation and comments on our suggestion (Carter and Challenor 1981) that it can be reduced by analysing monthly maxima instead of the usual technique of analysing annual maxima. Tabony gives a plot of annual maximum wind speed at Scilly in which he includes the distribution derived, as we suggest, by combining distributions of monthly maxima (his Fig. 11, reproduced here as Fig. 1). From this figure he concludes that: 'As the technique recommended by Carter and Challenor (1981) fails to provide a good representation of observed annual maxima, one can have little confidence in its use for

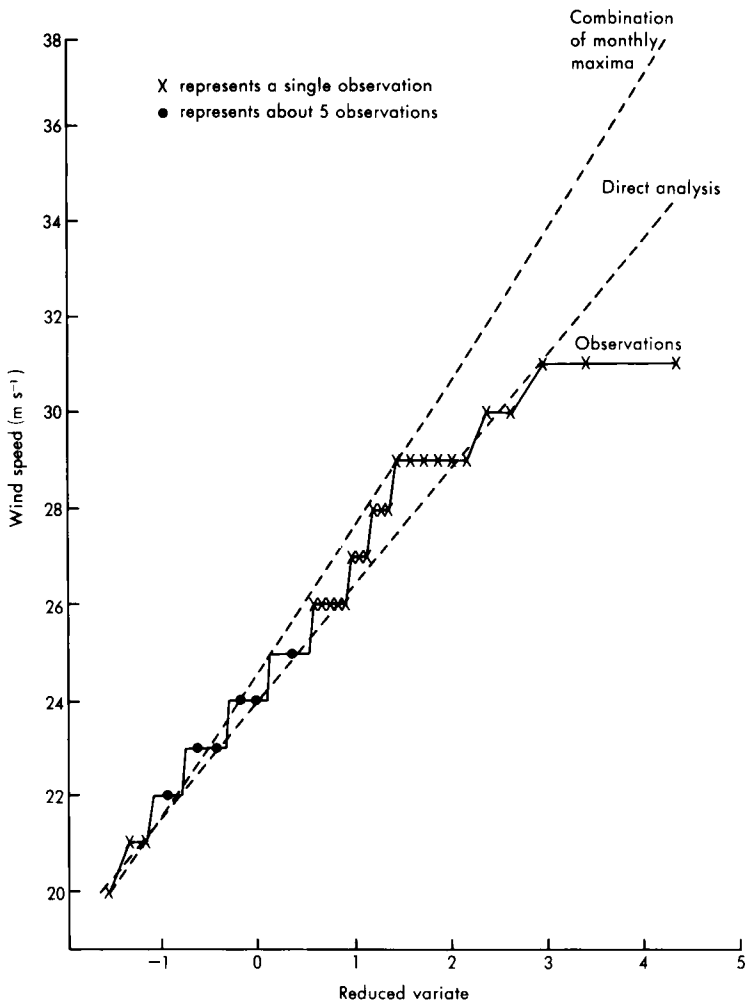

Figure 1. Annual maxima of hourly mean wind at Scilly, 1927–81.

purposes of extrapolation'. This statement would appear on the face of it to be a 'show stopper' worthy of Lady Bracknell. However, in matters statistical it is rarely wise to accept results at face value. It is in fact likely that 'our' distribution is closer to the true distribution of annual maxima than the product of 'direct analysis', and should be used for interpolation as well as for extrapolation, to estimate, for example, the 50-year return value.

Simulations from a simple model will show why this is so.

Simulation model

Suppose that maximum values during month m (m = 1–12) are from a Fisher–Tippett Type I (FT-I) distribution given by

$$\text{Prob}\,(X_{\max} < x) = \exp\{-\exp[-(x - A_m)/B_m]\} \qquad (B_m > 0). \qquad \ldots \quad (1)$$

So, assuming that monthly maxima are independent, the distribution of maxima throughout the year is given by

$$\text{Prob}\,(Y_{max} < y) = \prod_{m=1}^{12} \exp\{-\exp[-(y-A_m)/B_m]\} \qquad \ldots \quad (2)$$

Now assuming that A_m, B_m have the same values, A,B, for all months — so there is no seasonal variation in the model — then the distribution of annual maxima is given by

$$\text{Prob}\,(Y_{\max} < y) = [\exp\{-\exp[-(y-A)/B]\}]^{12}$$

which reduces to

$$\text{Prob}(Y_{max} < y) = \exp\{-\exp[-(y-(A + B\ln 12))/B]\} \qquad \ldots \quad (3)$$

i.e. annual maxima are also from an FT-I distribution with the same value for the scale parameter, B, but with A replaced by $A + B\ln 12$.

If we simulate maxima for each month for N years (i.e. $12N$ values), then the distribution of annual maxima can be estimated by:

(a) Fitting an FT-I to the N annual maxima to obtain estimates $\hat{A}$,$\hat{B}$, giving

$$\text{Prob}\,(Y_{\max} < y) = \exp\{-\exp[-(y-\hat{A})/\hat{B}]\}\text{, and}$$

(b) Fitting an FT-I to each of the 12 monthly sets of N maxima to obtain estimates $\hat{A}_m$, $\hat{B}_m$, then using equation (2) to give

$$\text{Prob}\,(Y_{\max} < y) = \prod_{m=1}^{12} \exp\{-\exp[-(y-\hat{A}_m)/\hat{B}_m]\}.$$

These two estimates for the distribution of annual maxima can be compared to the true distribution given by equation (3).

We have carried out such simulations, fitting the FT-I distributions by the method of maximum likelihood, and using A=B=1.

Results

The results of one such simulation run with N=40 are shown in Fig. 2, with probability axis scaled so that the FT-I distribution is linear. The data have been plotted using the same formula as that used by Tabony (1983a) for plotting position, with the ith ordered value of n at $(i-0.31)/(n+0.38)$. Clearly, method (a) gives a closer fit to the sampled annual maximum values — it must do, since this method consists simply of fitting these values; but the distribution obtained by method (b) is nearer to the true distribution of annual maxima.

It must be admitted that the example shown in Fig. 2 was not chosen quite at random, but was selected because of the similarity with Fig. 1. However, such a result is not uncommon. Figs 3(a) and 3(b) show the results of 50 random simulations; these figures give respectively the distributions estimated by method (a) and (b), with N=20. (Note that for clarity a narrow swath about the line of the true distribution has been left blank.) The right-hand edge of each plot, with probability = 0.99, gives the 100-year return value. Method (b) is generally close to the true distribution; the 100-year return value is biased high but its mean-square error is lower than the value from method (a), which suggests that method (b) is preferable. Similar results were obtained from simulations with other values of N (except that for small N, estimates of long-period return values from method (a) tend to be low because the method of maximum likelihood is biased for small N).

The results from these simulations would seem to imply that it is better to divide identically distributed data, analysing subsets such as monthly maxima rather than annual. More data are fully incorporated into the analysis, and the effects of outliers — statistical or accidental — are reduced. However, in practice the population distribution is not known, and the use of the FT-I is only justified asymptotically with increasing number of observations from which the maxima are derived. Unfortunately the rate of convergence to the asymptotic FT-I with increasing number of observations is not known, but Smith (1982) shows it to depend upon the (unknown) population distribution. So it is

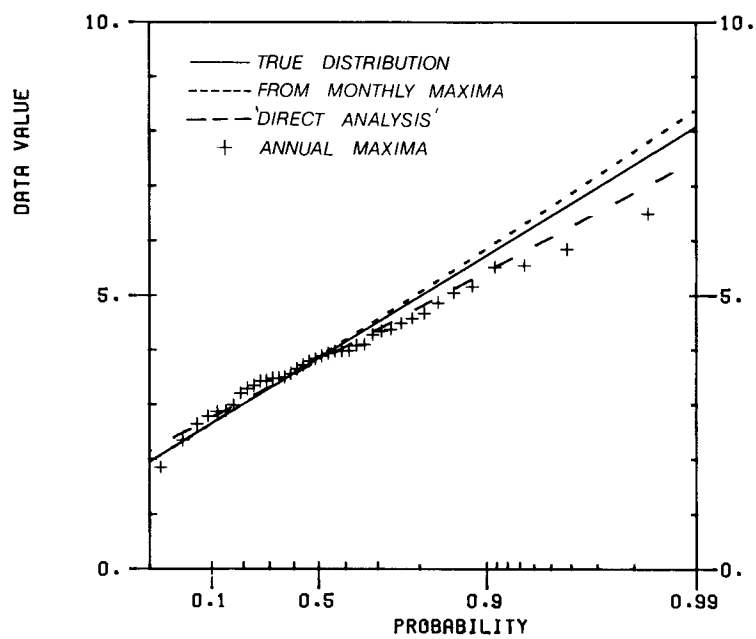

Figure 2. Example of estimates of the distribution of annual maxima from 40 years of simulated data.

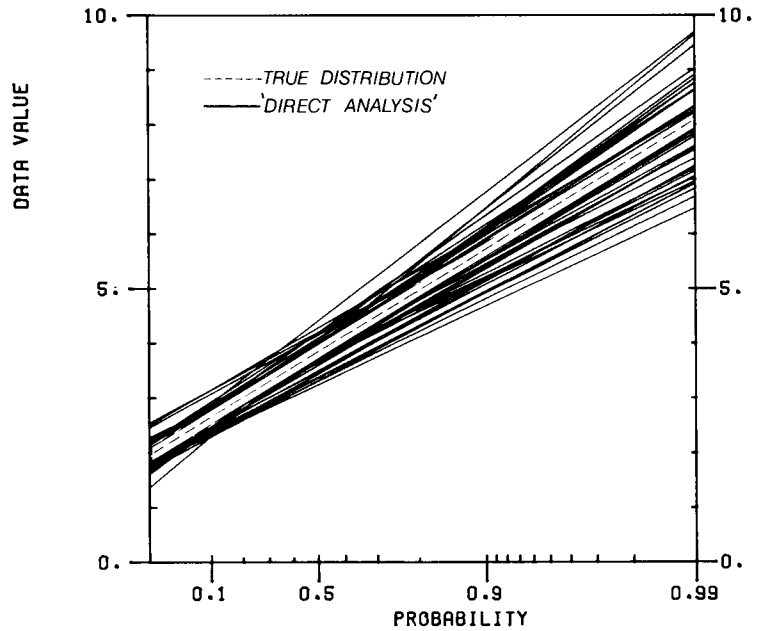

Figure 3(a). Fifty estimates of the distribution of annual maxima each from 20 years of simulated annual maxima.

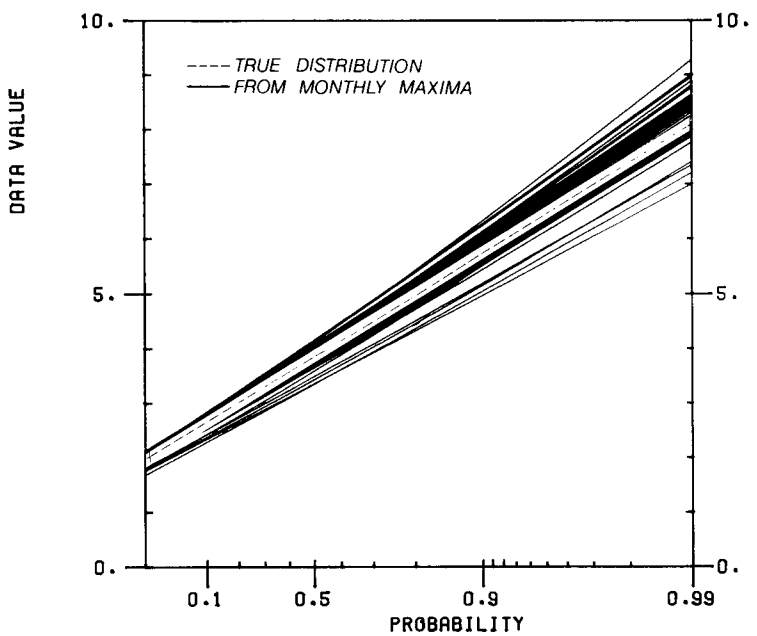

Figure 3(b). Fifty estimates of the distribution of annual maxima each from 20 years of simulated monthly maxima.

not possible to weigh the effect of improving the analysis by dividing the data into subsets against the consequent movement away from the asymptote. On the other hand, analysing annual maxima is not theoretically justifiable because of seasonal variation. In our reply to Tabony (1983b) in the *Quarterly Journal of the Royal Meteorological Society* we illustrate the markedly different distribution of wind speed at Scilly between months and show the effect of ignoring seasonal variation when estimating return values.

Our simulation model does not incorporate seasonal variation; even so the results illustrate why Tabony is wrong to infer from Fig. 1 that combining monthly maxima is an unsatisfactory method of estimating the distribution of annual maxima.

D. J. T. Carter
P. G. Challenor

Institute of Oceanographic Sciences
Wormley, Godalming, Surrey

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Tabony, R. C. 1983a Extreme value analysis in meteorology. *Meteorol Mag*, **112**, 77–98.

1983b Comments on 'Estimating return values of environmental parameters' by D. J. T. Carter and P. G. Challenor. *Q J R Meteorol Soc*, **109**, 893–894.

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Reply by R. C. Tabony

Conventional extreme value analysis of annual maxima requires a large amount of data before reliable results can be obtained. Very often, estimates of 50-year return values are required when only a few years of data are available, in which case estimates derived from annual maxima will have unacceptably wide confidence limits. In these circumstances it is sensible to use other techniques which reduce random errors by making use of more of the data. Such methods, however, may also be associated with larger systematic errors due, for example, to the main body of observations (which are used to reduce the random errors) not belonging to the same population as the extremes. The best technique to use may well be that which minimizes the total (systematic + random) error. Carter and Challenor's proposed technique, by making use of more of the data, produces smaller random errors than an extreme value analysis of annual maxima. They also claim, however, that their approach is associated with smaller systematic errors, and this is where we disagree.

In their comments, Carter and Challenor attempt to show the superiority of their technique by using simulated data. By not incorporating a seasonal variation they ensure that both monthly and annual maxima belong to a Fisher–Tippett Type I distribution and therefore that a direct analysis of the annual maxima will have no systematic errors. They show that estimates of 50-year return values obtained from a combined analysis of monthly maxima have a standard deviation about 70% of that obtained from a direct analysis of annual maxima. They also concede, however, that their technique introduces a small positive bias, although the extent of this is not clear from their diagram. I have performed a similar analysis using real data and a description of this follows.

Monthly and annual maxima of mean hourly wind during the period 1931–80 were extracted for the 9 stations shown in Fig. 1. Changes in effective height were taken into account by using a 0.17 power law relation, but other changes in site and instrumentation could not be allowed for, except during 1975 at Shoeburyness when overlaps were available. Occasional missing values were estimated from neighbouring stations.

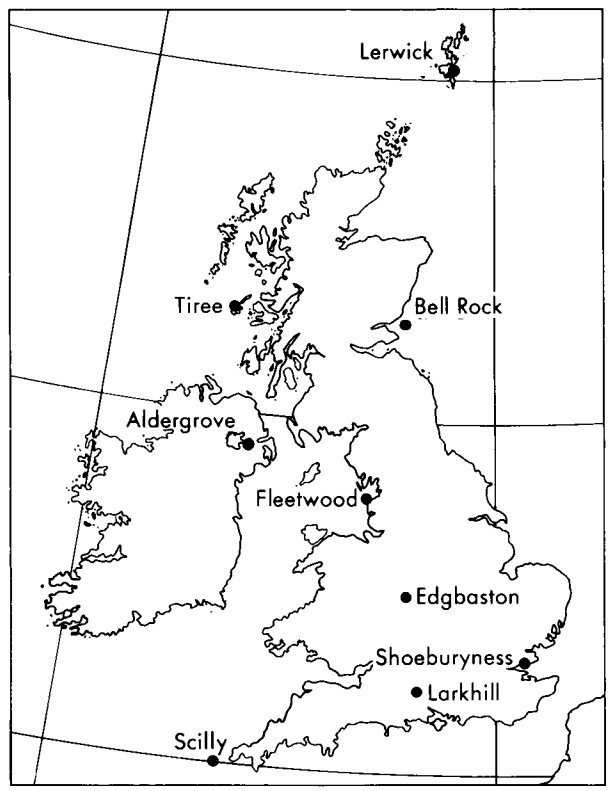

Figure 1. Stations used in the analysis

Return values of annual maxima were estimated both by a direct analysis of the annual maxima and by a combination of analyses of monthly maxima. The technique used was due to Lieblein (1974) and calculates the Gauss–Markov best linear unbiased estimates, which are those with the minimum variance for any linear estimate. The return values were obtained from only 10 years of data and were expressed as a percentage of the median annual maxima observed in the full 50 years of data for the station concerned. This procedure eliminated most of the differences between stations when the return values were expressed in absolute units. Forty-five sets of estimates were obtained (5 decades × 9 stations) and the means and standard deviations for various return periods are displayed in Fig. 2. These estimates are compared with a set of 'observed' annual maxima obtained by averaging the ranked extremes over the 9 stations after they had also been expressed as a percentage of the median value for each station.

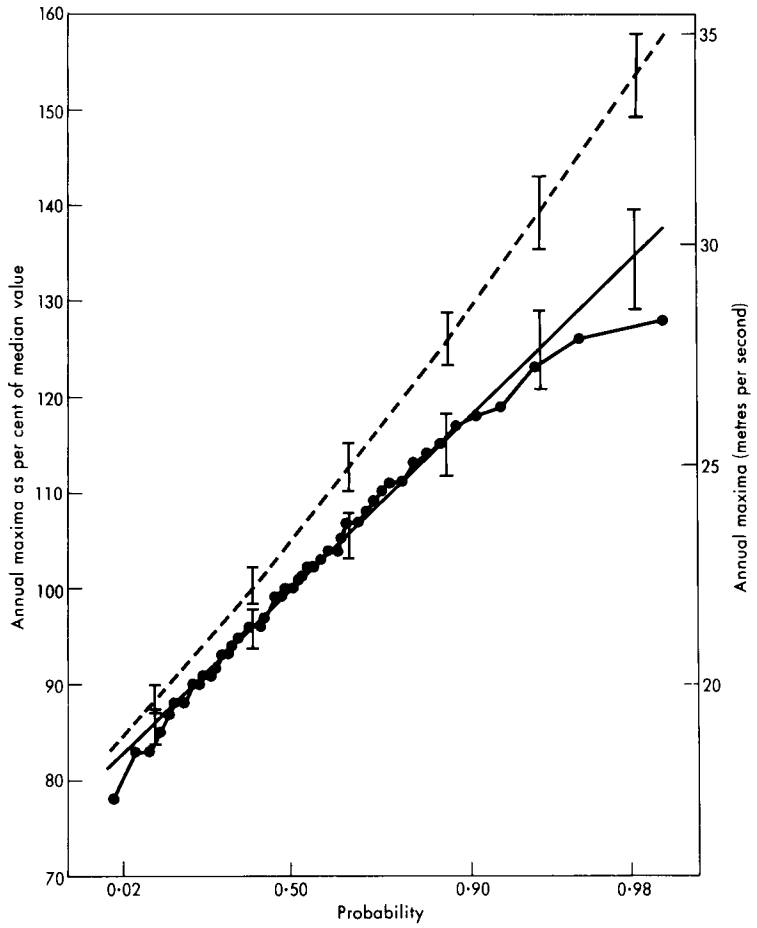

Figure 2. Annual maxima of mean hourly wind: comparison of 45 estimates made from 10 years of data for 9 stations over the period 1931–80.
——— Direct analysis of annual maxima.
— — — Recombination of monthly maxima.
●——● Observed data (meaned over 9 stations).
Vertical bars represent the standard deviation of the 45 sets of estimates.

Fig. 2 shows that a direct analysis of annual maxima provides a very good fit to the observed extremes, with very little systematic error. The presence of seasonal variation — the grounds on which Carter and Challenor criticize the analysis of annual maxima — is clearly unimportant. The combination of monthly maxima, on the other hand, yields estimates which are far too high, although their standard deviation is only 80% of that associated with the direct approach. The estimates in Fig. 2 are being tested against nearly independent data, since the former are derived from only 10 years of data for one station, while the observed values are based on 50 years of data from 9 stations.

There are two main reasons why a combined analysis of monthly maxima produces overestimates of annual maxima. The first may be expressed either as an inability to satisfy the asymptotic requirements of extreme value theory or else as the failure of the wide range of events represented by monthly maxima to

conform to a single population. These alternatives are statistically distinct but, as I tried to show in my paper, they are difficult to distinguish between in practice. Carter and Challenor (1983) show that, for certain parent distributions, a sample size of 10 is sufficient to meet the asymptotic requirements of extreme value theory. The number of independent meteorological observations in a month may average around 10, but in any individual month there may be more or fewer than this number, and months with persistent blocking patterns in particular may contain very few degrees of freedom. General meteorological experience indicates that a month is an insufficiently long period of time in which to observe an 'extreme' event.

The second reason why a combined analysis of monthly maxima overestimates annual extremes is essentially a random effect. Consider the case in which there is no seasonal variation, and all the monthly extremes belong to the same Fisher–Tippett Type I distribution. A sample of observations drawn from the population will yield monthly analyses whose slopes will not be equal, but which will be randomly distributed around the true value. The estimates of annual maxima will be asymptotic to the monthly analysis with the largest slope and this dependence on the largest, rather than the true slope, produces return values which are too high.

The question which now arises is: how much of the positive bias produced by the combined analysis of monthly maxima is due to each of the reasons given above? The errors caused by the second factor can be eliminated by ensuring a smooth seasonal progression of the slopes and intercepts of the extreme value distributions fitted to the monthly maxima. Thus the relative importance of the two effects can be determined by repeating the above analysis using smoothed 'regression coefficients' for the monthly analyses.

The slopes and intercepts of the 'Gumbel' distributions fitted to each month were expressed as a percentage of the value meaned over all months for the station concerned, and these values were then meaned over all stations. The results, displayed in Fig. 3, show a clear seasonal variation in the intercepts. The variation does not quite match the sine wave fitted by Challenor (1982), so a 7-point binomial filter was used to achieve the smoothing. This was actually applied to the median values rather

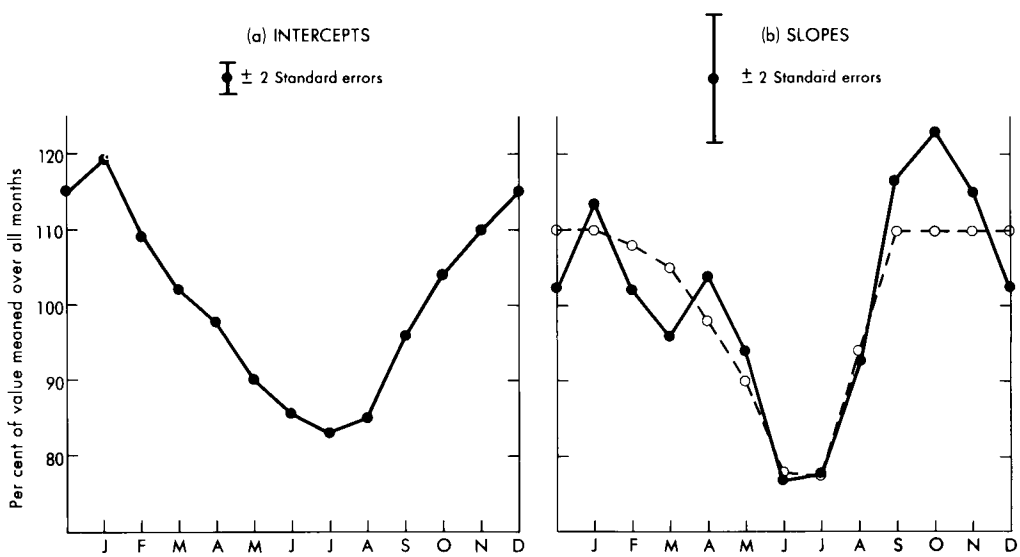
(a) INTERCEPTS
± 2 Standard errors
(b) SLOPES
± 2 Standard errors
Per cent of value meaned over all months
120
110
100
90
80
J F M A M J J A S O N D
J F M A M J J A S O N D

Figure 3. Intercepts and slopes of extreme value distributions fitted to monthly maxima of mean hourly winds (meaned over 9 stations). The dotted line indicates the imposed seasonal variation of slopes.

than to the intercepts, since the latter do not correspond to the centroid of observations. The much larger errors associated with the slopes ensure that the need for smoothing is great, but also that the true seasonal variation is unclear. The variation imposed is marked by the dotted line in Fig. 3(b) and combines a broad maximum from September to January with a sharp minimum in June and July. The true variation will probably change with geographical location, but the large errors involved prevent identification of any such changes.

The effect of smoothing the slopes and leaving the median values unchanged is shown in Fig. 4. It can be seen that the overestimate in the 50-year return value is almost halved and that a further modest reduction in error occurs when the median values are smoothed. The variance of the estimates, however, is unchanged by the smoothing. The general conclusion is, therefore, that random errors in the slopes of the monthly analyses account for nearly half the systematic errors in the return values of annual maxima.

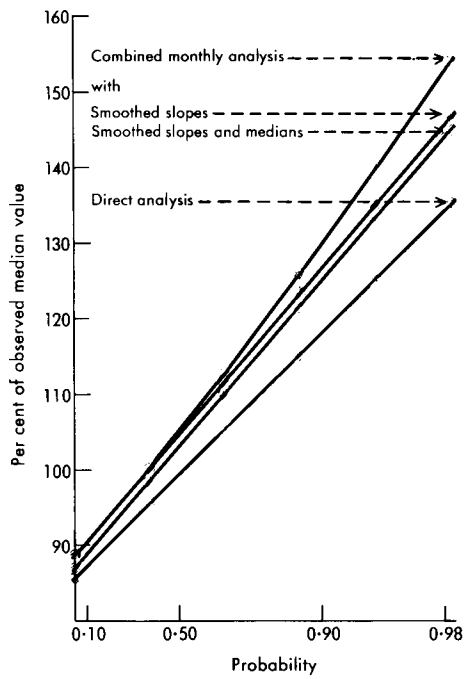

Figure 4. Comparison of estimates of annual maxima.

Despite the small systematic errors associated with the direct analysis of annual maxima, the large random errors involved may make it an unsuitable technique to use if only a small number of years of data are available. Every effort should be made, however, to reduce random errors by making use of covariate information, notably that from neighbouring stations. A comparison of results from neighbouring stations, combined with a sensible interpretation of them, should increase the applicability of extreme value techniques. Despite the fact that the incorporation of covariate information may have to be statistically crude, it still provides a very valuable way of reducing random error.

R. C. Tabony

Meteorological Office, Bracknell

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The Second International Meeting on Statistical Climatology

By R. C. Tabony

(Meteorological Office, Bracknell)

The meeting was primarily sponsored by the World Meteorological Organization and the USA's National Science Foundation and Office of Naval Research. It was held near Lisbon from 26 to 30 September 1983 and was attended by around 100 participants. The organizing committee chairman, Dr A. H. Murphy, worked hard to ensure that the conference program went ahead as smoothly as possible.

The scope of the meeting was wide, but subjects excluded from discussion were those relating to weather modification and forecasting, as these topics attract conferences in their own right. Subjects which featured prominently in this symposium were the economic value of climate information, the impact of climate, principal component and time series analysis, studies of precipitation, and the evaluation of general circulation model experiments. A total of 68 papers were presented, including 14 lead papers from invited speakers.

The standard of the lead papers was mixed. Some were very good, like that from Roger Stern who advocated an increase in the use of the general linear model. Others were poor in that they lacked generality, or covered only familiar ground and failed to highlight new areas of development or interest.

To the writer, some of the most interesting papers were those concerned with principal component analysis, especially the discussion relating to the assignment of variables to points in either space or time. These papers constitute highly recommended reading for the many users of this technique. Another area of interest was the evaluation of general circulation model experiments. There the discussion centred on how to determine the correct number of degrees of freedom from the massive amount of correlated data produced. This is clearly very important in order to avoid the inflated values of significance which have plagued climatology in the past. The last paper was given by Ian Jollife who pointed out that, for small sample sizes, the distribution of the correlation coefficient is flatter than that assumed by the formulae which are generally used for testing their significance. This goes a long way to explaining many of the spurious correlations which have been observed in climatology.

A large number of papers were concerned with simulation. The main reason for the exercise seems to be to reduce the sampling error by generating a long time series. In the writer's opinion, this is false logic. The sampling errors in the real data are converted to systematic errors in the simulation. Having thus generated the data, one is tempted to extend their use to provide information on aspects of the real world

which have not been modelled explicitly. Such use of a model is almost always likely to lead to gross errors. A much sounder technique is to fit distributions directly to the data in order to deal with the given enquiries. One then has a much better appreciation of the likely errors involved and there is no danger of using a model outside the area of its validity.

The main purpose of the meeting was clearly to promote an exchange of ideas between statisticians and climatologists, and this was most naturally achieved through lead papers and discussion periods. In general, this interchange of ideas was successful. Nearly half the lead papers were given by statisticians, where they were given the opportunity of recommending techniques suitable for climatologists to use. Papers presented by climatologists had their statistical weakness pointed out by the statisticians, while papers given by statisticians had their physical shortcomings exposed by the climatologists.

The interaction between statisticians and climatologists, however, should not consist solely of a flow of ideas from the former to the latter. In order to advance the cause of climatology, there needs to be a feedback of information to the statistician, and the climatologist cannot afford to adopt a passive role. All the statistical techniques used by the climatologist were developed with other disciplines in mind, e.g. medicine, agriculture, or the social sciences. The onus is on the climatologist to approach the statistician, inform him of his problems, and persuade him to carry out research into techniques of direct applicability to his science.

Statistical climatology has acquired a poor reputation in many eyes in recent decades. This had been mainly because of the low statistical standards of many papers, especially in the area of solar and climatic variability, which led Pittock to make his famous review*. Partly as a result, the era of statistically ignorant papers is largely, although not entirely, over. There are still too many papers, however, which one feels are cluttering the journals with trivia. The reasons are either that the aim is scarcely worth while, the results have no practical value, the scope is too limited, or that no attempt has been made to improve the quality of the data used to the extent that the results are useful. It is to be hoped that future meetings of this kind will have high amongst their aims the enhancement of the status of statistical climatology.

*Pittock, A. B. 1978 'A critical look at long-term Sun-weather relationships', *Rev Geophys Space Phys*, **16**, 400–420.

Notes and news

50 years ago

The following extracts are taken from the *Meteorological Magazine,* February 1934, **69,** 17, 20–21.

Buxton Weather Bulletin

Mr. H. Everard sends us the following copy of a weather bulletin which was displayed in a shop window at Buxton. In explanation of the remark about pressure it must be remembered that Buxton is at a height of 1,000 ft. above M.S.L.

Temperature. — Keeps up a good average.
Pressure. — Finds effort of climbing too much for it.
Rainfall. — Fairly frequent visitor.
Wind. — Speaks with a soft southern accent.
Current noting. — Ridge of high pressure giving way.
Further outlook. — Good, bad and indifferent in turn.
Propitious features. — Rest from their toils.
Ominous symptoms. — Collecting a representative array.

Today's local weather handicap.

Pressure — drooping once more.
Distant influences — still quarrelsome.
Inferences — Bashful sunshine.
Arrogant clouds.
General dampness.
Fair periods.
Fairly mild.

Broadcast Weather Noises

Now that weather noises "off" form such a usual — and vivid — accompaniment of many broadcast plays, meteorologists may be interested in the methods which are used in the studio for reproducing these realistic effects. Mr. J. E. Cowper has kindly supplied the following notes on the subject:—

Wind. — This is done on a cylinder 2 ft. in diameter and 6 in. deep, set in a wooden frame 3 ft. high with a length of canvas stretched over the top. A handle is fixed to this, and by rotating at a normal rate one gets a steady wind, and with a quick motion gusts. It is a most realistic noise, and usually comes over very well.

Rain. — A rose on a water tap is usually used for this, which is turned on fully into a large wooden tank.

Thunder. — This is produced by suspending from the ceiling a huge piece of sheet iron, with a wooden shaft at the bottom where two handles are fixed for the hands. This, when shaken in an intelligent way, produces excellent thunder.

Sea. — A one-sided drum with lead shot inside shaken from side to side and round and round produces waves breaking on the shore, and is quite one of the best noises "off."

May I add that in nearly all cases we use gramophone records of these sounds, and these records will, I think, gradually effect the instruments I have tried to explain to you.

Obituary

We regret to record the death on 7 September 1983 of Mr G. F. McKay, Higher Scientific Officer, who was stationed at London/Gatwick Airport.

Gerry McKay joined the Office as a Meteorological Assistant in 1947 and worked for some years at Castle Archdale in Northern Ireland. In 1952 he was posted to the Marine Branch at Harrow and in 1956 was promoted to Assistant Experimental Officer and became a forecaster. During his forecasting career he worked at a variety of outstations including Wittering, Upavon and Boscombe Down, with two lengthy spells at Heathrow (1956–61 and 1975–81) and an overseas tour at Laarbruch. He moved to Gatwick in 1981.

Gerry McKay had a cheerful and friendly personality and got on well with all his colleagues. He was a keen games player, especially in his younger days, being particularly good at lawn tennis. He used to compete in the Air Ministry championships, and represented Heathrow in matches against other Meteorological Office teams. He was a sportsman in the best sense of the term.

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